Weather Macroweather Climate

BIG AND SMALL, FAST AND SLOW: OUR RANDOM YET PREDICTABLE ATMOSPHERE

River Institute, Cornwall, May 2, 2018
Shaun Lovejoy
A voyage through scales

Zooming through scales by the billion

1mm - 10,000 km
A voyage through scales: Space, 0.1mm – 10,000km
A voyage through scales

Zooming through scales by the billion billion milliseconds to half a billion years
A voyage through scales: Time, 0.001s – 4.5 billion years

Zooming in time: Benthic Paleoindicators

Phanerazoic eon

Cenozoic era

Quaternary Period
Middle and Late stages Pleistocene epoch (EPICA, Antarctica)

Present

δ¹⁸O

Ice core

Upper stage Pleistocene epoch (GRIP Summit)

Ice core

Last glaciation

Last Millennium (Northern hemisphere)

Last interglacial (Holocene)

Age (kyr BP)

Date

Temperature (°C)

Ice ages

Hot

Cold

x8.8

x91

x4.8

x4.8

x91

x8.8
Dust Fluxes from an Antarctica ice core

Years before present

Length of series (years)

69

140

283

585

1250

2922

7100

15700

53600

126000

785000
Instrumental temperatures

Anthropocene (global, land, monthly)

The “Hockey stick”
Montreal Temperatures at increasing resolution

Fluctuations don’t cancel much
How to understand this mind-boggling variability?

(1): High level or low level laws?
Emergent laws: Which level?

Mechanics of a few particles → Statistical Mechanics: many particles → Collective behaviour of Thermodynamics, continuum mechanics, GCMs

Irrelevance of most of the details, collective behaviour of many, many components
The hierarchy continues

Continuum mechanics of a single vortex

Irrelevance of most of the details, collective behaviour of many, many components

Continuum mechanics of several vortices

Collective behaviour of many vortices: Turbulent laws

“spaghetti” picture
How to understand this mind-boggling variability?

(2): Deterministic or random?
Which Chaos?

How does God play dice??

...sorry Einstein!
Which Chaos?  
Stochastic or Deterministic?

Data, roof of physics building

Stochastic simulation (turbulent laws)

Deterministic simulation e.g. GCMs
Cosmos versus chaos through the ages

Chaos-Cosmos (ancient Greeks)

Scientific ideas about determinism and randomness

Determinism: God supplies the initial conditions (e.g. planets in orbits, Newton, 1670’s)
    “...if a sufficiently vast intelligence exists...” Laplace (1749-1827)

Chance: Ignorance, subjective
    “Chance is nothing” Voltaire: (1694-1778).

Chance: Irrelevance of the details
    Statistical Mechanics e.g. the bell curve distribution of molecular velocities in a gas
    (Maxwell, Gibbs, Boltzman, 1870-1900)

Chance: Objective
    Quantum Mechanics: Born interpretation of the wave function (1926)
    Mathematics: Kolmogorov axiomatized probability theory (1930)
The Nonlinear Revolution
1970 - 1990 - present

The Deterministic Chaos Revolution: The Butterfly Effect
-Tiny perturbations could be amplified
-Random looking phenomena might not be random after all…
-Backlash: an attempt to resurrect Newtonian determinism

The Stochastic Chaos alternative: scale symmetries, fractals, multifractals
-Objective randomness…
How to understand this mind-boggling variability?

(3): New worlds or scaling?
From Van Leeuwenhoek to Mandelbrot

Scalebound thinking and the missing quadrillion
Van Leeuwenhoek discovering a “new world” in a drop of water (circa 1690)
Mandelbrot (1924-2010) zooming into the Mandelbrot set

The Scaling view
Fractals sets
Cantor’s “Perfect” set (1870)

Self-similarity: a part resembles the whole
Zooming gives the same set!
“Holes” at all scales: Zooming gives on average the same sparseness of points

Lovejoy and Scherzter 1986
The dimension is not 2 but 1.75...

N = \text{(constant)} \times \text{diameter D}

D = 1.75

N = \text{average no. of stations in circle}

\text{diameter of circle (km)}
Scale invariance

Number of stations = \((\text{scale})^D\)

Average number of stations in a circle

Diameter of the circle

The relationship is the same at all scales: \textbf{scale invariant}

Ex:

Number of stations in a small circle = \((\text{small diameter})^D\)

Number of stations in a big circle = \((\text{big diameter})^D\)
Classifying atmospheric variability using Scale invariance

- What is the weather?
- Macroweather?
- What is the Climate?
The climate is not what you expect…

"Climate is what you expect, weather is what you get."


“Climate in a narrow sense is usually defined as the "average weather" ... 

- Intergovernmental Panel on Climate Change, 2007
The missing quadrillion: 1976 versus 2014

Atmospheric dynamics
1 hour- $10^9$ yrs: Mitchell 1976 (grey, bottom)

$E(\omega) \approx \omega^{-\beta}$

$\beta = 1.8$

Variability

Log$_{10}$E(\omega) vs. K$^2$yr

$10^{15}$

$10^{5}$

$10^{-5}$

$10^{-10}$

$10^{-9}$

$10^{-6}$

$10^{-5}$

$10^{-2}$

$10^0$

$10^2$

$10^4$

Billion years

Million years

Century

Decade

Year

Day

Hour
New simple technique discovered in 2012: Fluctuation analysis

Five Scaling regimes:
0.01 seconds - 550 million years
How does scaling help?

Scaling, scale invariance:

Typical Fluctuation $\approx (\text{scale})^H$

$H>0$: Fluctuations grow with scale, unstable
$H<0$: Fluctuations decrease with scale, stable

“The climate is what you expect, the weather is what you get”

Expect Macroweather!
Weather: $H>0$, macroweather, $H<0$, climate, $H>0$
Is civilization due to freak macroweather?

“The long, stable Holocene is a unique feature of climate during the past 420,000 years, with possibly profound implications for evolution and the development of civilizations.”
Petit et al., Nature, 1999, Based on the analysis of Vostok Antarctica cores

The Holocene is “highly unstable”.
Berner et al 2008, based on paleo Sea Surface Temperatures from ocean cores near Greenland.

“Have our species been spoiled by a long and blissful macroweather hiatus, or – on the contrary - did harshly varying climate adversity force us to invent new ways of coping?”

Sea Surface Temperature Holocene (ocean core, 1500 km distant)

Lovejoy and Schertzer 2013
Montreal,
November 2014

“Friends of Science” Versus Science

Montreal

Friends of Science

Association des Communicateurs Scientifiques

Ottawa

Global Warming

Stopped Naturally 16+ Years Ago
Usual (Bell curve probability): 1 in 3 million

Typical variation: 0.2°C

Residuals: 1880-2013

Pre-industrial

Industrial
The skeptics’ Giant Natural Fluctuation Hypothesis

What is the probability of a ≈1°C global temperature increase over ≈ 125 years?
Probabilities of extreme centennial temperature changes: Bell Curve, Black Swans

Usual representation

Post 1880 warming: \( \approx 1^\circ C = \frac{1}{0.2} = 5 \) standard deviations

Post industrial warming

\(-1.0 \quad -0.5 \quad 0.5 \quad 1.0\)

\( \Delta T (^\circ C) \)

\( 2.0 \quad 1.5 \quad 1.0 \quad 0.5 \quad 0.2 \quad 0.05 \quad 0.01 \quad 0.001 \)

\( \text{Probability} \)

Global temperature (dashed)

Bell curve (Gaussian)

Representation showing extremes

Post industrial warming

Global temperature (dashed)

\(-1.0 \quad -0.5 \quad 0.5 \quad 1.0\)

\( \Delta T (^\circ C) \)

\( 1\% \quad 0.1\% \quad 0.01\% \quad 0.001\% \quad 0.0001\% \)

\( \text{Probability} \)

\( = 5 \) standard deviations: one in 3 million chance

Algebraic fall-off of probability

one in 3 thousand chance
Climate closure

In the battle of public opinion over climate change, we can play to science's strengths by shifting tactics: Instead of struggling to prove humans are to blame, let's prove denialist fantasies wrong.

A straightforward line of reasoning demonstrates that the only viable explanation of postindustrial warming is an anthropogenic source. This explanation is compatible with the "pause" in the warming since 1998, and it demonstrates that, in a statistical sense, such a pause is extremely likely. Credit: Shawn Lovejoy

By: S. Lovejoy  © 20 October 2015
The skeptics reaction

Friends of Science (Calgary based group)

...Friends of Science are also calling up the Chancellor of McGill University to retract the McGill press release and issue an apology for the use of Lovejoy's quote “This study will be a blow to any remaining climate-change deniers..."

"This is not the language of science or good taste that one expects from a Nobel Laureate university," says Gregory.

Viscount Lord Christopher Monckton of Brenchley:

“A mephitic ectoplasmic emanation of the forces of darkness”

A mephitic ectoplasm
Scaling and (elephantine) memory: forecasts and projections
The basic GCM limitation and macroweather forecasting \((\approx 10\text{ days to decades})\)

Weather systems (<10 days) generated by GCMs
= random weather noise (statistics)...
but not fully realistic

Model climate

Our climate

Scaling, stochastic models: use data to force convergence to the real climate.

The “killer app” for atmospheric scaling?

StocSIPS

Stochastic Seasonal and Interannual Prediction System
Visit our site

http://www.physics.mcgill.ca/StocSIPS
Global Warming

Stopped Naturally 16+ Years Ago.

FIND OUT MORE AT: FRIENDSOFSCIENCE.org

The “Pause”
The MME versus historical projection methods. Shaded areas are the 90% confidence limits.
Our future: climate projections
IPCC versus Historical based projections
90% uncertainty limits

IPCC

2050

2.6
Carbon Capture and Storage

4.5
Realistic?

8.5
Business as usual

2.6
All IPCC projections are within the 2°C threshold

2100

“Simple”: without memory, “SCRF”: Scaling Climate Response Function, with memory

Lovejoy, Hebert, 2018
Predicting the 2013 temperature... in 1909!

Actual global temperature

90% uncertainty limits

Prediction based only on knowledge of CO₂

T (°C)

0
0.5
1.0
1.2

1900 1909 1950 2000 2020

0.22 °C

Lovejoy 2015
Projections: 2080-2100

Historical

IPCC

Scenarios

Low emissions (RCP 2.6)

Moderate emissions (RCP 6.0)

RCP= Representative Carbon Pathways

RCP 2.6: Massive Carbon Capture and storage, strong mitigation, 2.6 W/m² of extra warming in 2100

RCP 6.0: moderate mitigation, 6.0W/m² of extra warming in 2100
Difference: GCM’s- Historical Method

- Warmer than predicted
- Cooler than predicted
- X’s: significant differences

The map shows the temperature differences between historical methods and GCM predictions. The color scale represents temperature changes in °C due to CO₂ doubling.
Conclusions

Huge range of scales: time and in space

Emergence: high level versus low level laws
- Turbulence Laws: collective behaviour

Which Chaos: Stochastic or deterministic?

Scalebound or scaling?

Classifying: Weather, climate… and macroweather!

Climate Closure

Mars: sister planet, statistical twin

Scaling and memory: forecasts, projections
CLIMATE
SUMMIT

WHAT IF IT'S A BIG HOAX AND WE CREATE A BETTER WORLD FOR NOTHING?

- ENERGY INDEPENDENCE
- PRESERVE RAINFORESTS
- SUSTAINABILITY
- GREEN JOBS
- LIVABLE CITIES
- RENEWABLES
- CLEAN WATER, AIR
- HEALTHY CHILDREN
- ETC. ETC.